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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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| <b>(51) International Patent Classification <sup>6</sup> :</b><br><b>B32B 5/12, H05K 7/20, F28F 7/00, 13/18</b>   | <b>A1</b> | <b>(11) International Publication Number:</b> <b>WO 99/67088</b><br><b>(43) International Publication Date:</b> 29 December 1999 (29.12.99)  |
| <b>(21) International Application Number:</b> PCT/US99/12543<br><b>(22) International Filing Date:</b> 4 June 1999 (04.06.99)<br><br><b>(30) Priority Data:</b><br>09/103,416      24 June 1998 (24.06.98)      US<br><br><b>(71) Applicant:</b> JOHNSON MATTHEY ELECTRONICS, INC.<br>[US/US]; 15128 Euclid Avenue, Spokane, WA 99216 (US).<br><br><b>(72) Inventors:</b> PINTER, Michael, R.; East 504 Midway Road,<br>Colbert, WA 99005 (US). DEAN, Nancy, F.; 1827 South<br>Liberty Drive, Liberty Lake, WA 99019 (US). WILLETT,<br>William, B.; South 7220 Cedar Road, Spokane, WA 99224<br>(US). GETTINGS, Amy; 10923 East 37th, Spokane, WA<br>99206 (US). SMITH, Charles; 2915 Sunset Hills Road,<br>Escondido, CA 92025 (US).<br><br><b>(74) Agent:</b> GIOIA, Vincent, G.; Christie, Parker & Hale, LLP, P.O.<br>Box 7068, Pasadena, CA 91109-7068 (US). |           | <b>(81) Designated States:</b> CN, JP, KR, SG, European patent (AT, BE,<br>CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC,<br>NL, PT, SE).<br><br><b>Published</b><br><i>With international search report.</i> |
| <b>(54) Title:</b> TRANSFERRABLE COMPLIANT FIBROUS THERMAL INTERFACE<br><br><div data-bbox="548 1129 1023 1281"></div><br><b>(57) Abstract</b><br><p>Described is a transferrable fibrous thermal interface. The interface comprises flocked thermally conductive fibers (32) embedded in an adhesive in substantially vertical orientation with portions of the fibers extending out of the adhesive. An encapsulant (30) fills spaces between the portions of the fibers that extend out of the adhesive (34) and a release liner is on at least one outer surface of the interface.</p>  |           |  |

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1 TRANSFERRABLE COMPLIANT FIBROUS THERMAL INTERFACE

BACKGROUND OF THE INVENTION

5 A popular practice in the industry is to use thermal grease, or grease-like materials, alone or on a carrier to transfer the excess heat across physical interfaces. However, the performance of these materials breaks down or deteriorates when large deviations from surface planarity cause gaps to form between the mating surfaces or when large gaps between mating surfaces are present for other reasons, such as variation in surface heights, manufacturing tolerances, etc. When the heat transfer ability of these materials breaks down, the performance of the component to be cooled is adversely affected. The present invention provides fibrous interfaces that deal effectively with heat transfer across physical interfaces.

BRIEF DESCRIPTION OF THE DRAWINGS

15 FIGS. 1A, 1B and 1C are schematic views showing electroflocked fibers in adhesive, pushed into the adhesive and resulting in more or less even fiber lengths extending from the adhesive; and

FIG. 2 is a schematic showing encapsulant between fibers and the free-fiber tips.

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SUMMARY OF THE INVENTION

In one aspect of the invention there is provided a fibrous interface material sandwiched between two layers of a removable paper or release liner. The interface comprises flocked, e.g. electroflocked, mechanically flocked, pneumatically flocked, etc., thermally conductive fibers embedded in an adhesive or tacky substance in substantially vertical orientation with portions of the fibers extending out of the adhesive. An encapsulant is disposed to fill spaces between portions of the fibers that extend out of the adhesive, leaving a free fiber structure at the fiber tips.

30 Another aspect of the invention is a method of making a fibrous interface. In the method, thermally conductive fibers of desired length are provided and, if necessary, cleaned. A release liner is coated with an adhesive or tacky substance, and the fibers are flocked to that release liner so as to embed the fibers into the adhesive or tacky substance with a portion of the fibers extending out of the adhesive. The adhesive is cured and the space between fibers is filled with a curable encapsulant. A second piece of release liner is placed over the fiber ends. Then the fibers in the adhesive with the release liner over the fibers in the adhesive with the encapsulant in the spaces between the fibers is compressed to a height less than the normal fibers' length and clamped at the compressed height. Thereafter the encapsulant is cured while under compression to yield a free fiber tip structure with the fiber tips extending out of the encapsulant.

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1 (Alternatively, the adhesive and encapsulant may be cured concurrently, or the adhesive not cured, as hereafter discussed.)

## 5 DETAILED DESCRIPTION OF THE INVENTION

An interface material advantageously possesses a low bulk thermal resistance and a low contact resistance. A suitable material is one that conforms to the mating surfaces, e.g. wets the surfaces. The bulk thermal resistance can be expressed as a function of the material's thickness, thermal conductivity and area. The contact resistance is a measure of how well a material is able to make contact with a mating surface. This thermal resistance of an interface can be written as follows:

$$\Theta_{\text{interface}} = \frac{t}{kA} + 2 \Theta_{\text{contact}}$$

15 where  $\Theta$  is thermal resistance  
 $t$  is material thickness  
 $k$  is thermal conductivity of material  
 $A$  is area of interface

20 The term  $\frac{t}{kA}$  represents the thermal resistance of the bulk material and  $2 \Theta_{\text{contact}}$  reflects thermal contact resistance at the two surfaces.

A good interface material should have low bulk resistance and low contact resistance, i.e. at the mating surfaces.

Many applications require that the interface material accommodate deviations from surface flatness resulting from manufacturing, and/or warpage of components due to coefficient of thermal expansion (CTE) mismatches.

25 A material with a low value for  $k$ , such as a thermal grease, performs well if the interface is thin, i.e.  $t$  is low. If the interface thickness increases by as little as 0.002 inches, the thermal performance can drop dramatically. Also, for such applications, differences in CTE between the mating components causes this gap to expand and contract with each temperature or power cycle. This variation of the interface thickness can cause pumping of fluid interface materials (such as grease) away from the interface.

30 Interfaces with a larger area are more prone to deviations from surface planarity as manufactured. To optimize thermal performance, the interface material must be able to conform to non-planar surfaces and thereby lower contact resistance.

Optimal interface materials possess a high thermal conductivity and a high mechanical compliance, e.g. will yield elastically when force is applied. High thermal conductivity reduces the first term of Equation 1 while high mechanical compliance reduces the second term. An

1 aligned thermally conductive fibrous material can accomplish both of these goals. Properly  
oriented, the thermally conductive fibers will span the distance between the mating surfaces  
thereby allowing a continuous high conductivity path from one surface to the other. If the fiber  
is flexible and able to move in its tip region, better contact can be made with the surface. This  
5 will result in an excellent degree of surface contact and will minimize the contact resistance of  
the interface material.

To distribute or allow external heat dissipation, an interface material can be applied  
between the component to be cooled and an external heat dissipating device such as a heat sink.  
The interface material then accommodates manufacturing induced deviations from planarity from  
10 both the cooled component and heat dissipating surface component. The interface material may  
be applied to either the heat dissipating surface, e.g. heat sink, heat pipe, heat plate,  
thermoelectric cooler, etc. or to the cooled component surface. The heat dissipating device may  
be attached to the cooled component through the use of spring clips, bolts, or adhesive, etc. in  
any conventional manner.

15 The interface material may be made as follows:

Suitable thermally conductive fibers such as diamond fibers, carbon fibers, graphite fibers,  
metal fibers, e.g. copper fibers and aluminum fibers, are cut to length, e.g. from 0.0005 to about  
0.250 inches and having a diameter greater than about 3 microns up to 100 microns. Presently,  
fibers of about 10 microns diameter are preferred. Desirable fibers have a thermal conductivity  
20 greater than about 25 W/mK. Fibers of the type that are useful include those available Amoco  
identified as K-1100, K-800, P-120, P-100, P-70 and T50; as well as fibers available from Toray  
designated M46J and M46JB.

The fibers are cleaned, if necessary. Cleaning the fibers tends to remove any coatings  
present on the fibers. Some commercially available fibers are sold with a coating applied to the  
25 surface which is preferably removed by cleaning. One method of cleaning is by heating the  
fibers in air to burn off the coating, i.e. sizing. However, chemical cleaning methods can be also  
used.

To produce an interface, first an adhesive or tacky material is applied to a release liner or  
waxy silicone coated paper or other sheet material. Alternatively, a transfer tape material that  
30 is typically available in sheet or roll form and includes an adhesive pre-applied to a release liner  
or carrier may be used. The release liner or coated paper may be either electrically conductive  
or thin enough (less than 0.005 inches) so as not to inhibit the generation of an electrical field  
with a metal backing plate. Advantageously, the adhesive will produce a low stress bond or  
adherence. This can be a tacky substrate comprising a silicone gel (e.g. RTV6166 from General  
35 Electric Corporation), although uncured epoxy, gels, gasket materials, silicones, organosilicones,  
BMI, or cyanate esters are also useful.

The fibers are flocked to an adhesive, thereby embedding the fibers in the adhesive, as  
shown in FIG. 1A, for example by electroflocking. Electroflocking is a well-known procedure

1 whereby two plates, separated some distance, are charged to opposite polarity. The procedure  
is described generically by Bolgen (Bolgen Stig W., "Flocking Technology", Journal of Coated  
Fabrics, Volume 21, page 123, 1991) and specifically for electroflocking of carbon Fibers by  
5 Shigematsu in "Application of Electrostatic Flocking to Thermal Control Coating", Proceedings  
of the 14th International Symposium on Space Technology and Science, 1984, page 583; and by  
Kato in "Formation of a Very Low-reflectance Surface by Electrostatic Flocking", Proceedings  
of the 4th European Symposium on Space Environmental and Control Systems, 1991, page 565.  
The disclosure of these articles is expressly incorporated herein by reference.

10 In the electroflocking process, fibers on one plate pick up that plate's charge and become  
attracted to the opposite plate. They embed in the adhesive when they hit the opposite plate. If  
they do not stick initially, fibers bounce back and forth between plates until they become  
embedded in the adhesive, or escape the electric field or the charge on the plates is removed.  
The fiber structure that results is aligned with respect to the electric field lines, i.e. has a  
substantially vertical orientation, and has a velvet-like appearance.

15 Mechanical flocking involves passing an adhesive coated object over a series of rapidly  
rotating rollers or beater bars, which cause the substrate to vibrate. Fibers are fed onto the  
substrate by gravity from a hopper. The vibrations produced by the rollers or beater bars orient  
the fibers and drive them into the adhesive. Excess fiber is removed, leaving a fiber structure  
with substantially vertical orientation.

20 Pneumatic flocking uses an airstream to deliver fibers to an adhesive coated surface.  
While in flight, fibers align themselves in the direction of the airflow and embed in the adhesive  
in an oriented manner.

Different flocking methods may be used alone, or in conjunction with one another, e.g.,  
pneumatic/electrostatic flocking. With this combination method, an airstream containing fibers  
25 is directed through a nozzle. At the exit of the nozzle, a charge orients the fibers with respect  
to electric field lines. The fiber structure that results is also aligned, i.e., has substantial vertical  
orientation, but may be denser, more uniform or produced more rapidly than when either method  
is used alone.

30 The flocked fibers are seated into the adhesive with a portion of their lengths extending  
from the adhesive layer, referred to as "free fiber tips". After flocking, a downward force is  
applied to the free fiber tips to seat the fibers in the adhesive and minimize the distance between  
the fiber tips embedded in the adhesive and the release liner to which the adhesive is applied, as  
shown in FIGS. 1B and 1C.

35 The adhesive, or tacky substance, is then cured, e.g. by self-curing or application of heat.  
Oftentimes heating for about 30 minutes at about 150° C may be used for curing, depending on  
the adhesive and curing conditions.

As shown in FIG. 2, an encapsulant, 30, for example a gel such as GE RTV6166 dielectric  
gel available from General Electric Corporation is introduced to fill space between fibers 32

1 leaving free fiber tips 34 extending from the gel. This can be done by stenciling uncured gel  
onto the fibers or applying the gel to the fibers and letting the gel soak or wick in. It is  
advantageous to use a gel that spontaneously wets the fibers and will wick into the fiber  
structure. The gel may or may not include a thermally conductive filler material. A release liner,  
5 i.e. waxy or silicone coated paper may be placed on top of the fibers and uncured gel to prevent  
the cured gel/fiber material from sticking to a clamping fixture, and provide protection to the  
interface material during shipping or subsequent handling.

The interface material with uncured gel between the fibers is compressed to less than the  
nominal cut fiber length and clamped in place to this compressed height. For example, if the  
10 fiber is about 0.020 inches long, adhesive cured gel is introduced then clamped to a height of  
about 0.017 inches before curing the gel which holds the fiber at this height while the gel is  
cured.

A second release liner of, for example waxy or silicone coated paper, is placed on top of  
the gel and fibers. This top release liner serves to prevent the gel from sticking to fixtures used  
15 during compression and also provides protection during shipping or subsequent handling.

The gel is then cured, e.g. thermally cured, while under compression. Heating generally  
accelerates curing and is desirable to create a beneficial free-fiber tip structure. Both the  
compression and thermal cure aid in creating the free-fiber tip structure. The thermal cure is  
beneficial since the CTE of the gel is higher than that of the fibers and the gel will shrink more  
20 than the fibers upon cooling to room temperature, thereby exposing more fiber tips.

In producing the interface material, the adhesive curing may be delayed to coincide with  
the curing of the gel. In this case, the fibers are seated at the same time as the gel and the  
adhesive are cured. As indicated, compression is beneficial, and curing under compression is  
beneficial, because the gel will maintain the cured thickness and the fibers can spring back  
25 somewhat to stick up from the gel. Cohesion of the gel to the fibers is not strong enough to keep  
the fibers from assuming their original position prior to curing. This results in the free fiber tips  
which are desirable for enhanced thermal contact with the adjacent surface(s).

The interface material, sandwiched between two sheets of release liner, may be cut or  
stamped to the desired shape using conventional methods (e.g., steel rule die cut), after the  
30 desired shape is cut. For use, the first release liner is removed and the tacky adhesive is attached  
to one of the physical interface surfaces. The second release liner, if present, may then be  
removed and the two components to be interfaced put together.

It is apparent from the foregoing that various changes and modifications may be made  
without departing from the invention. Accordingly, the scope of the invention should be limited  
35 only by the appended claims, wherein:

## 1 WHAT IS CLAIMED IS:

1. An interface comprising a free fiber tip structure capable of transferring heat between two bodies and at least one release liner, said free fiber tip structure comprising flocked, thermally conductive fibers embedded in an adhesive in substantially vertical orientation with portions of the fibers extending out of the adhesive and an encapsulant between the portions of the fibers that extend out of the adhesive and beneath the free tips of the fibers.

2. An interface according to claim 1 wherein said fibers comprise one of carbon fibers, graphite fibers, metal fibers, ceramic fibers and diamond fibers.

3. An interface comprising a free fiber tip structure with at least one release liner, said free fiber tip structure comprising flocked thermally conductive fibers embedded in an adhesive in substantially vertical orientation with portions of the fibers extending out of the adhesive and encapsulant disposed between the portions of the fibers that extend out of the adhesive and beneath the free tips of the fibers, said release liner comprising a removable laminate on the adhesive layer capable of removal prior to adhering the interface to a body.

4. An interface according to claim 3 wherein the release liner is on the adhesive.

5. An interface according to claim 3 comprising a release layer on opposite surfaces of the interface.

6. A method of making a semiconductor assembly comprising:

- a) providing thermally conductive fibers of desired length;
- b) applying adhesive to a coated paper or release liner;
- c) flocking the fibers to an adhesive and embedding said fibers into the adhesive with a portion of the fibers extending out of the adhesive;
- d) curing the adhesive;
- e) applying another piece of coated paper or release liner to the tops of fibers with encapsulant;
- f) disposing a curable encapsulant between fibers extending out of the adhesive and beneath the free tips of the fibers;
- g) compressing the fibers with encapsulant between the fibers into the adhesive to less than the nominal fiber length and clamping to the compressed height;
- h) curing the encapsulant while under compression to yield a free fiber tip structure with fiber tips extending out of the adhesive; and
- i) interposing the free fiber tip structure between a component to be cooled and



1 a heat sinking device.

7. A method according to claim 6 wherein said adhesive comprises a release liner.

5 8. A method according to claim 6 further comprising interposing a release liner between the uncured encapsulant and fiber prior to curing the encapsulant.

9. A method according to claim 6 wherein in step (g) said encapsulant in step (d) is cured under compression during step (g).

10 10. A method according to claim 6 wherein the fibers comprise one of carbon fibers, graphite fibers, metal fibers, ceramic fibers and diamond fibers.

11. A method according to claim 6 wherein the fibers are electroflocked to the release liner.

12. A method according to claim 6 wherein the fibers are pneumatically flocked to the release liner.

13. A method according to claim 6 wherein the fibers are mechanically flocked to the release liner.

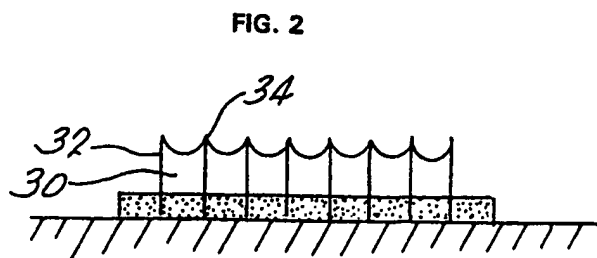
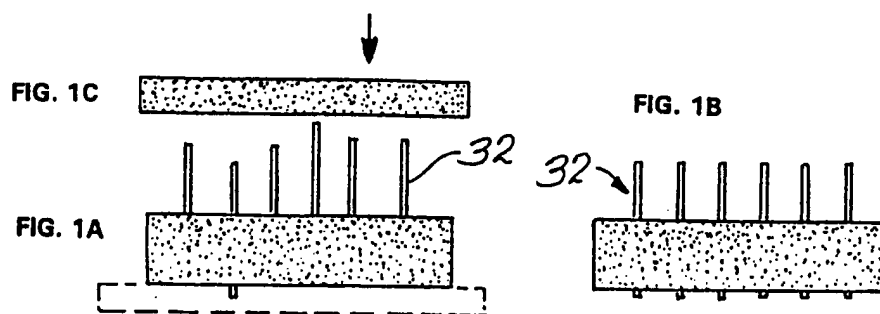
14. A method according to claims 1 and 6 wherein the adhesive and encapsulant are cured substantially simultaneously.

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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US99/12543

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) :B32B 5/12; H05K 7/20; F28F 7/00, 13/18

US CL :Please See Extra Sheet.

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 428/86, 90, 96, 112, 408; 174/16.3, 17VA; 361/704, 707; 165/.....; 427/206

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, DERWENT

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category*      | Citation of document, with indication, where appropriate, of the relevant passages   | Relevant to claim No. |
|----------------|--|-----------------------|
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| Y              | WO 97/28044 A1 (BERENS et al.) 07 AUGUST 1997, page 2, line 19 - page 3, line 17; page 4, line 19 - page 5, line 13; page 6, lines 1-10; and page 7, lines 1-10. | 1-5                   |
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☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

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Date of the actual completion of the international search

09 SEPTEMBER 1999

Date of mailing of the international search report

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## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                  | Relevant to claim No. |
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| Y         | US 5,077,637 A (MARTORANA et al.) 31 DECEMBER 1991, abstract and col. 5, lines 1-8.                                 | 1-5                   |
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# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US99/12543

## A. CLASSIFICATION OF SUBJECT MATTER:

US CL :

428/86, 90, 96, 112, 408; 174/16.3, 17VA; 361/704, 707; 156/ 62.2, 160, 161, 272.4; 427/206